10/583515
IAP12 Rec'd PCT/PTO 16 JUN 2006


# METHOD AND APPARATUS FOR DETERMINATION OF CENTRAL AORTIC PRESSURE

## FIELD OF THE INVENTION

The present invention relates to the determination of central aortic systolic and pulse pressure from a peripheral waveform.

## BACKGROUND OF THE INVENTION

The relationship between systolic blood pressure in the arm and cardiovascular events is well established, and is the basis for modern therapy for hypertension. Such therapy, aimed at reducing brachial systolic pressure, has been very successful in reducing death and disability from cardiovascular events.

However, the brachial systolic and pulse pressure may differ significantly from the corresponding values in the aorta and central arteries. Measurements of central aortic systolic and pulse pressure have been demonstrated as superior to brachial pressure in correlating with severity of existing disease and prediction of subsequent events. Such studies have used direct pressure measurements during cardiac catheterisation, or estimates of pressure from the carotid pressure or diameter waveform. Another measurement approach is described in US Patent No. 5,265,011 to O'Rourke, whereby central systolic and pulse pressure can be determined from a peripheral pressure waveform using a transfer function.

Whilst the latter method has proved highly successful in practice, it requires reasonably complex processing. In order to enable the determination of central aortic systolic and pulse pressure from a peripheral site, using a relatively simple instrument, it would be advantageous to provide a simpler method requiring a less sophisticated processing approach.

## SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a method for determining central systolic pressure, comprising the steps of:

determining a time t from pressure wave foot to peak in a central carotid artery;

measuring a radial pressure waveform; and

locating the pressure wave foot in the radial pressure waveform and determining the corresponding pressure at time t after the wave foot;

wherein said corresponding pressure is substantially the central systolic pressure.

According to a second aspect of the present invention there is provided a method for determining central systolic pressure, comprising the steps of:

measuring a radial pressure waveform;

locating the time of start of a component of said waveform attributable to lower body wave reflection; and

determining the central systolic pressure by taking the value of the pressure waveform at said time.

Preferably, the start of the component attributable to lower body wave reflection is determined by analysing the waveform to locate the inflection in the waveform attributable to lower body reflection.

Preferably, the methods can be implemented in software for programming an apparatus to carry out the methods.

The present invention was derived from careful consideration of the underlying processes. In human adults, under normal conditions, the peak of the aortic pressure wave is usually in late systole, some 150 ms or more after initial upstroke of the pulse. In contrast, the peak of the pressure wave in the upper limb usually occurs much earlier, some 90 - 130 ms after the initial upstroke of the wave. The difference in waveform between the two sites is attributable to differences in timing of wave reflection in the lower body and upper limb. The aortic peak is largely due to the later return of wave reflection from the distant lower body, whereas the upper limb peak is due to summation of early reflected waves from within the upper limb itself. Recognition of such differences lead to the present invention.

A practical advantage of the present invention is that it allows for relatively accurate determination of the central aortic systolic pressure without requiring the application of a transfer function or a similar complex technique.

**BRIEF DESCRIPTION OF DRAWINGS**

Implementations of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 illustrates the waveforms associated with an exemplary implementation of the first aspect of the present invention;

Figure 2 illustrates an example radial artery pressure waveform;

Figure 3 illustrates a flow chart of an exemplary implementation of the second aspect of the present invention;

Figures 4a to 4e illustrate variants of radial artery waveforms associated with the method illustrated in Figure 3.

**DESCRIPTION OF PREFERRED EMBODIMENTS**

The present invention will be described with reference to illustrative embodiments. It will be appreciated that the invention is not confined to any particular physical implementation.

In the present invention, the pulse pressure is determined in the same manner as systolic pressure, but is calculated as the systolic pressure minus the diastolic pressure, so as to give the amplitude of the wave. Consequently, the exemplary system of the present invention preferably comprises means for calculating the pulse pressure from tonometer measurements and the calculated central systolic pressure wave, such as a simple processor having computer software loaded therein for carrying out the calculations.

An exemplary implementation of the first aspect of the present invention requires the measurement of both the carotid and radial pressure waveforms in order to determine the central (aortic) systolic pressure. Figure 1 shows pressure waveforms measured non-invasively from the carotid artery and from the upper limb. The upper limb waveform is measured, for example, at the radial artery. Time t is shown, representing the time from wave foot to peak in the carotid waveform. At this time t from the foot of the radial waveform, the initial peak has passed and the waveform shows the broad peak associated with the lower body reflections. The pressure value at this time in the radial waveform is a close

approximation to the systolic pressure value in the aorta. The radial waveform is calibrated using, for example, conventional brachial cuff techniques.

It will be understood that determining the time t from the wave foot to peak is a simple matter of determining the time from minimum to maximum value, which can be readily captured by a simple digital system. The time t can then be applied to a captured data set of pressure against time, in order to find the pressure time t after the minimum value in the radial waveform. A practical implementation is straightforward for a suitably skilled electronic engineer. Display of the radial or carotid waveforms is not required.

Accordingly, this implementation of the first aspect of the present invention relies on locating the broad peak using timing information from central (carotid) arteries and detecting the radial pressure value where it corresponds to the central pressure. It will be appreciated that this method requires measurement of pressure or diameter in a central artery, in order to acquire the timing information, and this measurement is ideally made under similar conditions to the radial tonometry. Any suitable sensing arrangement may be used, provided a sufficiently accurate timing can be extracted.

On the other hand, an exemplary implementation of the second aspect of the present invention only requires measurement of the brachial or radial waveform in order to determine the central (aortic) systolic pressure. Specifically, this implementation excludes the effects of wave reflection in the upper limb and identifies the reflected wave from the lower body, which normally comprises the peak of pressure in the ascending aorta.

This is accomplished by analysing derivatives of the upper limb pressure waveform, so as to identify the peak of the pressure wave which returns from the lower body, and which constitutes the late systolic surge of pressure after the initial peak. The time T2 denotes the peak of this wave. Brachial or radial pressure at T2 is peak aortic systolic pressure (ASP) and aortic pulse pressure is ASP minus brachial or radial diastolic pressure.

The first, second and third derivatives of upper limb the pressure wave are analysed for this purpose, as outlined in the flowchart in figure 3. First, the peak

of the waveform is identified. Then a search is conducted for any local minimum of the first derivative before the peak of the recorded pressure wave. If a local minimum of the first derivative is present, then T2 is set at the peak of the recorded wave, and this is taken to represent peak aortic systolic pressure; when this occurs the pressure peak is generated well after peak flow in the artery, and so more than 150 msec after the wave foot. Ideally, the local minimum of the first derivative is detected by determining whether there is a zero crossing from negative to positive in the second derivative.

If there is no localised minimum of the first derivative before the peak of the wave, then there is a search for the first zero crossing from positive to negative of the second derivative after the peak of the recorded wave and before the incisura. If there is a zero crossing, then this is taken to represent T2 and pressure of the recorded wave at this point is taken to represent peak aortic systolic pressure. There will always be a zero crossing at the time of incisura (that is, at the beginning of diastole). As shown in Figure 2, the incisura normally occurs quite late in the waveform (more than 250ms after the initial wavefoot, well after peak flow in the artery, and hence it is necessary to exclude the incisura from being detected. Thus the search for the zero crossing can be practically restricted to within the first 40% of the waveform.

If the second derivative shows no zero crossing from positive to negative after the peak of the wave, then there is a search for the last zero crossing from positive to negative of the third derivative up to or at the peak of the recorded wave. If there is a zero crossing, then T2 is set at the peak of the recorded wave. If there is no zero crossing, then there is a search for the first zero crossing from positive to negative of the third derivative after the peak of the recorded wave and T2 is set at the time of this zero crossing and the pressure of the recorded wave at this point is taken to represent peak aortic systolic pressure.

The application of this process is shown in the five recorded radial artery pressure waveforms in figure 4. As can be seen, for each of waveforms 1, 2 and 3 a secondary systolic or reflected wave is apparent in the upper limb. In these three waveforms, the time T2 (at which radial artery pressure approximates aortic

peak pressure) occurs after the peak of the recorded wave and is identified from the second differential. In the waveform 5, the peak of the wave occurs in late systole and is preceded by a local minimum of the first derivative. The peak constitutes T2 and the peak pressure approximates that in the aorta. In waveform 4, there is no apparent separate reflected wave in the upper limb, but the peak of the pressure wave occurs more than 150 msec after the foot of the wave, and the third derivative shows a localised zero crossing. For waveforms 4 and 5, peak pressure occurs more than 150 msec after the wave foot, while for waveforms 1, 2 and 3, the peak occurs earlier than 150 msec, and corresponds to the peak of flow in the artery.

The above described processor may preferably determine whether the differentials need to be calculated based on the determination of the timing of a reflected wave, and returns the aortic systolic pressure value accordingly.

It will be appreciated that variations and additions are possible within the spirit and scope of the invention.